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14. ABSTRACT

This report results from a contract tasking Slovak Academy of Sciences as follows: The contractor will investigate a cross-calibration of coronal measurements from the three worldwide coronal observing stations (Lomnicky Stit (Slovakia), Sacramento Peak (USA), and Mt. Norikura (Japan)). The contractor will obtain data on current and past measurements from his own records and the public domain. The goal of this investigation is a fully verified long-term coronal database that will be used to address long-term evolution of the solar atmosphere, the solar wind, space weather, and terrestrial climate. The final report will contain this database.

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FINAL SCIENTIFIC REPORT

FOR EOARD CONTRACT F61775-01-WE048

„COMPARISON AND CROSS-CALIBRATION OF THE GREEN CORONAL DATA FROM ASTRONOMICAL INSTITUTE OF THE SLOVAK ACADEMY OF SCIENCES WITH MEASUREMENTS FROM CORONAL STATIONS AT SACRAMENTO PEAK OBSERVATORY (USA) AND NORIKURA (JAPAN)"

1. Introduction

The long-term evolution of the Sun on decadal and longer time scales is of great interest for both space weather and the Sun/climate connection. Various indicators such as sunspot numbers and levels of geomagnetic activity indicate that the Sun has been increasingly active during the past century. For example, annual averages of the geomagnetic aa index at the minima of recent solar cycles exceed those observed at maxima of solar cycles early in the 20th century. Since the solar wind originates in the corona, it is particularly important to have long-term measures of coronal variability. The longest continuous series of high-confidence coronal measurements has been made at the Astronomical Institute of the Slovak Academy of sciences, from 1965-present. Comparable observations began at Sacramento Peak Observatory (jointly operated by the USAF and NSO) since 1973, however, published in Solar Geophysical Data from 1977. The Slovak observations at Lomnický štít coronal station have consisted of measurements of the emission-line corona in ions of iron formed near 1 MK (Fe X) and 2 MK (Fe XIV, the green line). These only other observatories in the world that currently make such synoptic measurements of the green emission line corona are Mt. Norikura in Japan and Kislovodsk in Russia.

In addition to our own records, we have gathered data from other earlier no-longer-operating coronagraphs to compile an extensive and exclusive data base (Rybanský et al., Solar Phys., 152, pp 153-159, 1994) of coronal observations covering the period since 1947 (less-complete data extend back to the earliest coronal observations in the late 1930s). Data from this long-term coronal data set have been be used to study the large-scale distribution of solar activity in the corona and for comparison with cosmic rays, etc. From the coronal data, we have calculated a coronal index of solar activity (CI) that gives an irradiance measure of the coronal green line emission. This index has exhibited monotonically increasing values at the peak of the last five solar cycles (18-22); only for the most recent cycle, does the CI look to be leveling off. This result, of course, has implications both for space weather and global warming. The peak cycle CI did not mimic the behavior of peak sunspot numbers for the last five cycles. In particular, the peak sunspot number of cycle 20 was only about 120, compared with 190 for cycle 18 and approximately 160 for each of the last two cycles.

The goal of the research proposed here would be to compare the Slovak and Sacramento Peak data bases for periods of overlap to confirm the reality of the increase in the long- term data base, taking into account all differences in the measurements made at the various stations,

e.g., the height above the limb at which the green line measurement is made, as well as differences in the data reduction procedures, in particular the calibration procedures. Preliminary comparisons of the data (Solar Phys. 152, 487-495, 1994; Contributions of the Astronomical Observatory Skalnate Pleso 27, 25-30, 1997; Solar Phys. 184, 317-322, 1999; Contributions of the Astronomical Observatory Skalnate Pleso 29, 105-110, 1999) show that the two data sets are qualitatively comparable but do not address the question of the quantitative differences between them. Once the relationship between the data from the US or other coronal station and Slovakia is established, the lessons learned in the cross-calibration process would be applied to the earlier data sets to obtain a homogeneous long-term coronal record. In addition, cross-calibrations will be applied to data from Kislovodsk and Mt. Norikura as well. The resulting homogeneous data set can then be confidently compared with other direct and indirect measures of solar activity such as the sunspot number, solar X-ray and the 2800 MHz radio fluxes, and/or geomagnetic and cosmic ray indices.

The end product of such research would be a fully verified long-term coronal data base that can be used to address long-term evolution of the solar atmosphere, the solar wind, space weather, and terrestrial climate.

2. Input data and analysis

Coronal intensities as obtained at individual coronal stations over the world differ for many reasons (the observed above the solar surface, method of observation: spectrum or monochromatic picture, method of photometry, etc.), hovewer, the most important is calibration and its stability in the longer period. As a final result, each coronal station has its own corona over cycle, sometimes with a different course regarding to the other ones. To decide what photometry of the green corona is correct, minimum three coronal station have to be in operational state, or, high correlation coefficient between the green corona intensities and above mentioned solar or cosmicray indices can decide, what coronal data are correct. This problem occurred especially before 1965 when no coronal data we have had for our disposal, and some coronal stations provided only relative coronal data, e.g. Arosa (Switzerland), and Climax USA), or coronal observations lasted for a short period, e.g. one solar cycle, e.g. Kanzelhohe (Austria) or Wendelstein (Germany) or Climax or Sacramento Peak (both in USA). In order to extend our photometric scale before the 1965 in a correct way, we needed to compare all available data between coronal stations that observed in these period, and also compare the green coronal data with the course of sunspots, the 2800 MHz flux and cosmic rays. Several papers presented in the last period have shown a good correlation between the green corona intensities and solar magnetic flux, the green corona and cosmic rays (an inverse course for known reason), the green corona and sunspots, so the green corona should extend their values for the period when these indices were not observed, e.g., magnetic flux from 1976 back to 1939, or, using sunspot data, the CI should be extrapolated back to 1815. To do all above discussed questions, and prepare final analysis, we needed firstly to gather or available data into the digital form. These data were published in Quarterly Bulletin on Solar Activity, or in Solar Geophsical Data. Unfortunately, the Sacramento Peak data in digital form was not released for this study, and we have had to obtain them from a graphical form to the digital form, or downloaded from Sacramento Peak www page. Nevertheless, the stated target was successfully done, and some preliminary results have been already published or presented in international meetings. We note the modified data before 1965 as well as in chosen periods after 1965 will be on www page, similarly as coronal

intensities from some other coronal stations. Following work has been done before above mentioned analysis:

1/ Collection of all coronal data from Climax coronal station (USA) in the period 1943-1957. Data in the period 1947-1954 was observed and published in relative units, in 1955-1965 calibrated units.

2/ Data from Sacramento Peak Observatory were transformed from graphical form into the digital form in the period 1977-2002.

3/ Collection of all coronal data from Kislovodsk coronal station (Russia). This station has been added into the programm due to its long duration in observations of the green corona intensities, and the highest correlation with our data after the 1965.

4/ Collection of all data from Pic du Midi Observatory (France), in 1943-1974.

5/ Collection of all data from Norikura coronal station (Japan) in 1951-1997.

6/ Collection of data from Wendelstein (Germany) – period 1947-1978, and Arosa (Switzerland) – period 1939 – 1974 coronal stations. These station have been also added to our analysis to have as more as possible observational data in 1939-1976 years.

7/ Correlations between the coronal index of solar activity and other solar indices have been made for the last years (1996-2000), and obtained results show very good correlations, especially with total solar irradiance.

3. Results

We have made very nice progress sorting out the calibration differences in the world wide patrol between the coronal network consisting of stations in Mt. Norikura (Japan), Kislovodsk (Russia), Sacramento Peak and Climax (USA), Arosa (Switzerland) as well as the Astronomical Institute of Slovakia's station in Lomnicky Stit. In particular, obtained results indicate that the absolute intensities measured by the Japanese station are too low by a factor of about three, while the values recorded at our own Sac Peak station have been too high by about a factor of ~50% during this last solar maximum. Corrections can now be made to these measurements. Moreover, correlations between coronal intensity and other solar/interplanetary parameters (e.g., sunspot number, cosmic ray intensity, the 10-cm radio peak flux density) now allow one to infer coronal conditions back to ~1815. A paper on this work is being prepared for the Astrophysical Journal.

Now that a well-calibrated homogeneous data set is available going back to 1939 (based on actual coronal observations, taking earlier data Climax (USA), Pic du Midi (France), and Arosa (Switzerland)), with a more limited extrapolation back to 1815, it will be possible to exploit this data set for space weather forecasting purposes. Obtained results can investigate such topics as active solar longitudes, coronal rotation variation with the solar cycle (important for recurrent storm forecasting), and long-term predictions of the phase of solar maximum and minimum, minimum to 2050. On the other hand, the reexamined data did not confirmed monotonically increase of the CI since 1947 to 1996 as computed from incompletly coronal data. The CI course has very similar course to that of sunspots, the 2800 MHz flux or cosmis rays (inverse course) in the searched period 1939-2002. This comparison also showed

unstable photometry at Sacramento Peak Observatory over searched period, similarly as the 'wild' calibration at Pic du Midi in cycle 20 (1965-1974), especially in the years 1970-1974.

4. Oral or poster presentations:

1/ Vojtech Rušin, Milan Rybanský and Milan Minarovjech:
The 530.3 nm corona irradiance from 1939 to 2001, presented at World Space Congress and 34th COSPAR Scientific Assembley, October 10-20, 2002, Houston, USA.

2/ Vojtech Rušin and Miloslav Druckmuller:
The Messina December 4, 2002 white-light corona, presented at „TOTALITY DAY 2003" , (February 8, 2003), Open University, Milton Keynes. UK.

3/ Vojtech Rušin, Milan Minarovjech, Milan Rybanský and Edward W. Cliver:
Reexamination of the coronal index of solar activity before the year 1965, presented at „Solar Variability as an Input to the Earth Environment, ISCS Symposium June 23-28, 2003, Tatranská Lomnica, Slovakia.

5. Papers (ready and accepted for publications):

1/ Vojtech Rušin, Milan Rybanský and Milan Minarovjech, 2003,
The 530.3 nm corona irradiance from 1939 to 2001, COSPAR Proceedings , in press.

2/, Vojtech Rušin, Milan Minarovjech, Milan Rybanský and Edward W. Cliver, 2003,
Reexamination of the coronal index of solar activity before the year 1965, ESA Publication (The Netherlands), in press.

3/ Milan Rybanský, Milan Minarovjech and Vojtech Rušin, 2003, **Evolution of the green corona in 1996-2002**, Solar Physics, in press.

6. Paper in preparation:

1/ Milan Rybanský, Vojtech Rušin, Milan Minarovjech and Edward W. Cliver, 2004,
Reexamination of the coronal index of solar activity form 1939 to 2002, in preparation.

Final remark:
New coronal data will be used in the wide range of solar community and space weather scientists, when released.

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